

(12) UK Patent Application (19) GB (11) 2 371 578 (13) A

(43) Date of A Publication 31.07.2002

(21) Application No 0201645.9

(22) Date of Filing 25.01.2002

(30) Priority Data

(31) 60264353

(32) 26.01.2001

(33) US

(71) Applicant(s)

Baker Hughes Inc
(Incorporated in USA - Delaware)
3900 Essex Lane, Suite 1200, PO Box 4740, Houston,
Texas 77210-4740, United States of America

(72) Inventor(s)

Edward J Zisk Jr

(74) Agent and/or Address for Service

Murgitroyd & Company
Scotland House, 165-169 Scotland Street,
GLASGOW, G5 8PL, United Kingdom

(51) INT CL⁷

E21B 43/12

(52) UK CL (Edition T)

E1F FLF FLK F304

(56) Documents Cited

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(58) Field of Search

UK CL (Edition T) E1F FLE FLF FLH FLJ FLK FLM

INT CL⁷ E21B

Online: WPI, EPODOC, PAJ

(54) Abstract Title

Sand screen with active flow control

(57) A tool for regulating the rate of fluid flow from an earth production zone comprises a flow control zone 23 through which fluid from the production zone is channelled. Preferably the flow control zone 23 is formed in an annular space between a central bore 11 and a surrounding production tubing 21. Within the flow control zone is a flow control device which selectively restricts the flow of fluid through it, and two sets of ports 24, 26, the first upstream of the device and the second downstream. Both sets of ports allow fluid to flow into the central bore 11 to carry the fluid to the surface and are selectively opened and closed. The control device comprises circumferentially placed stator columns 30 in the flow channel which can selectively interlock with sliding gate plugs 36, such that when they are engaged fluid cannot flow past, and the first set of ports 24 are open. Disengagement of the stator columns 30 and gate plugs 36 simultaneously closes the first set of ports 24 and allows fluid to flow beyond the stator columns. Downstream the fluid encounters a helically wound wall 28 which acts to reduce the fluid flow rate, before passing through the second set of ports 26 into the central bore 11. In an intermediate position both sets of ports are closed. In alternative embodiments the ports are opened and closes by electrically actuated solenoid valves or valves controlled by shape memory alloy, which reacts to the temperature of the fluid.

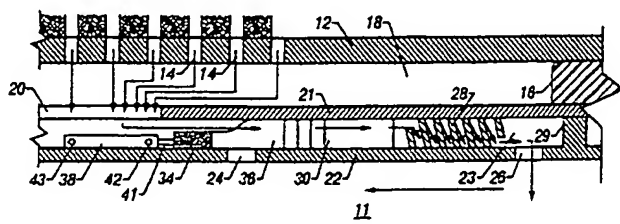


FIG. 2

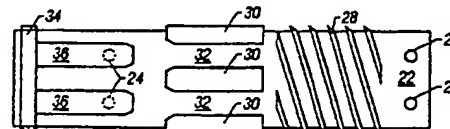
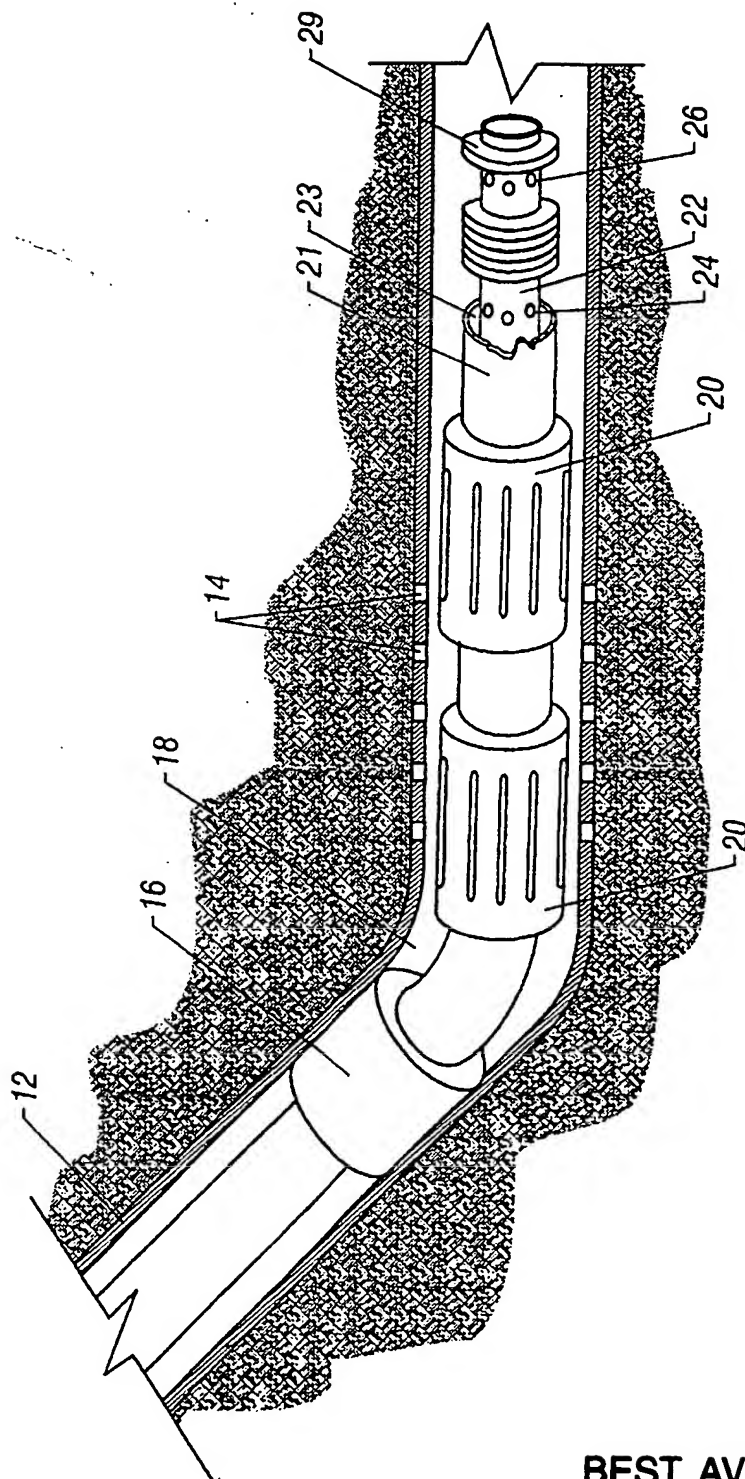


FIG. 5

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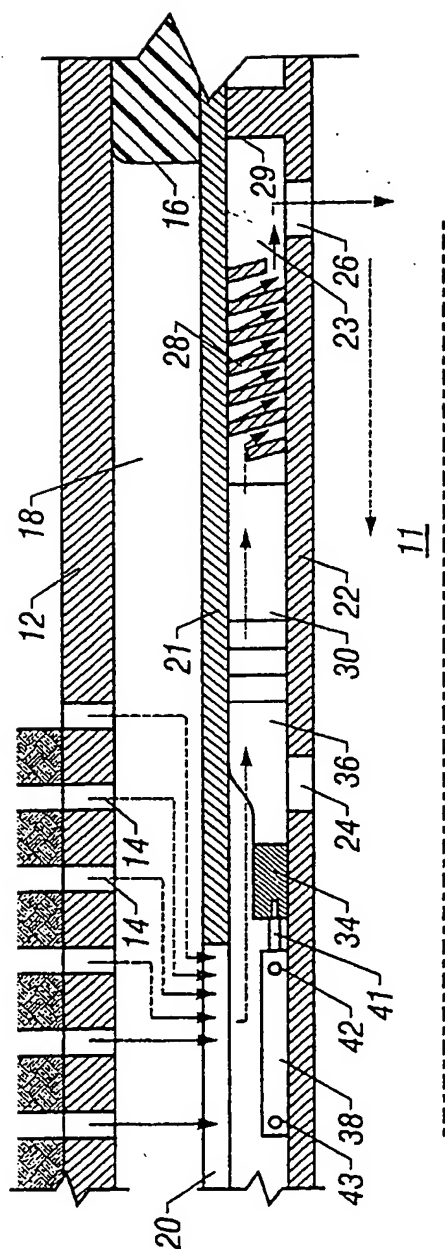


FIG. 2

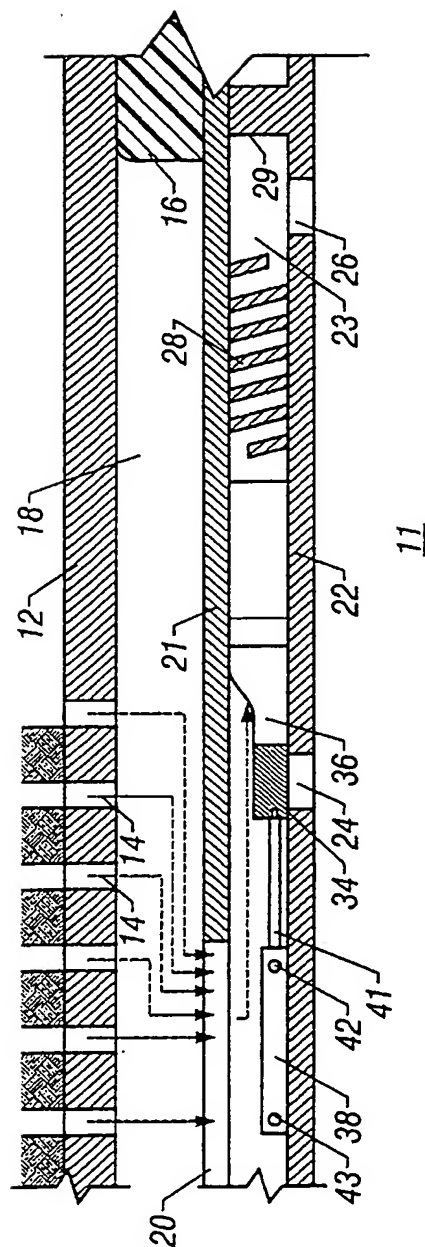


FIG. 3

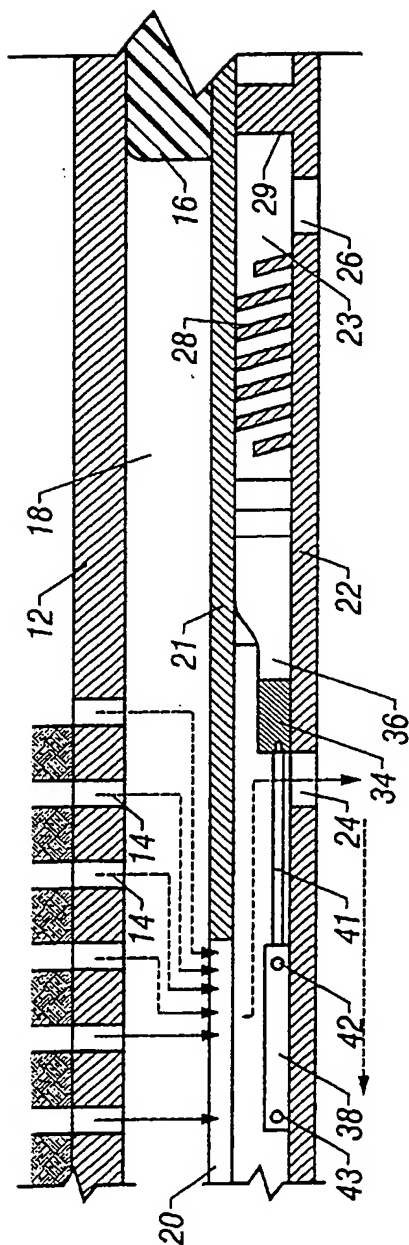


FIG. 4

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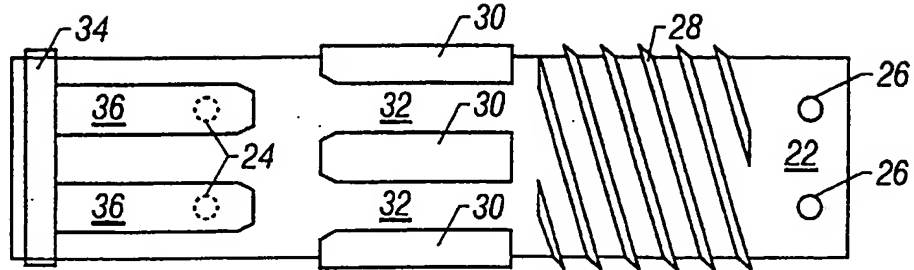


FIG. 5

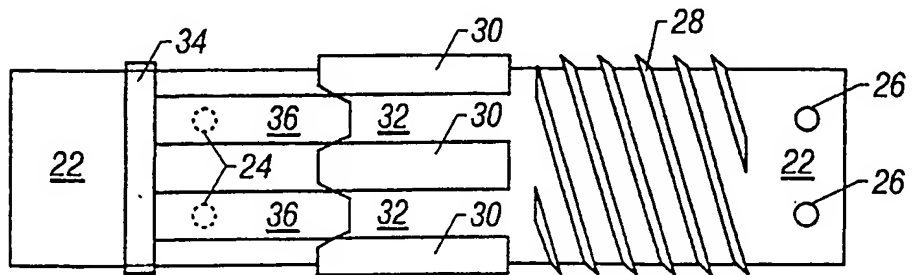


FIG. 6

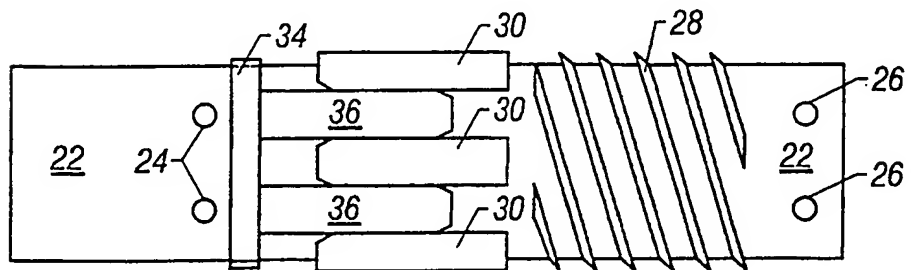


FIG. 7

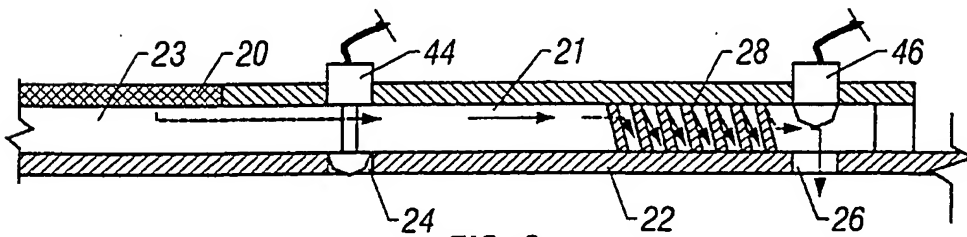


FIG. 8

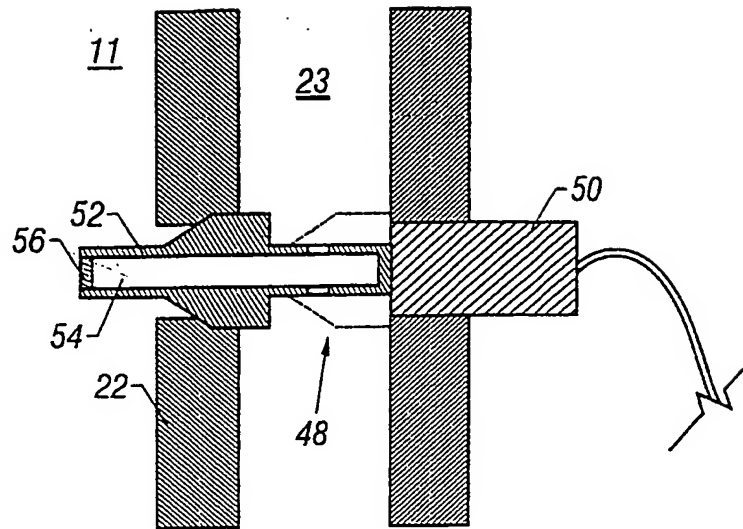


FIG. 9A

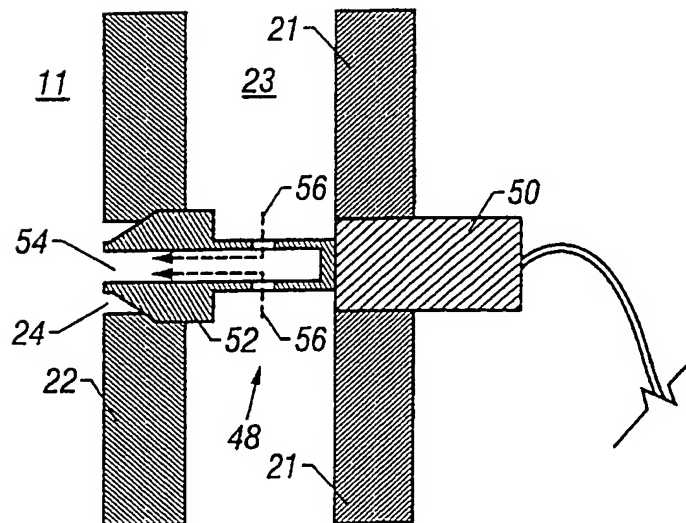


FIG. 9B

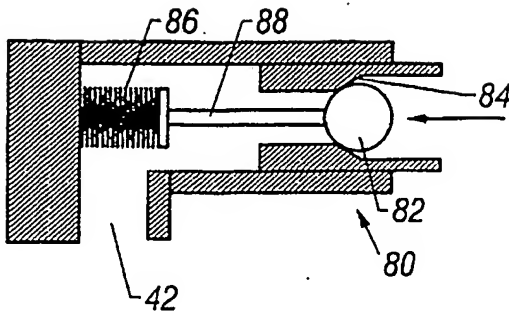


FIG. 10A

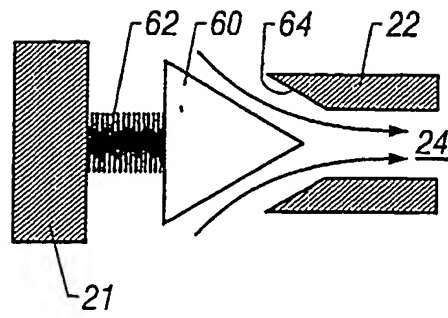


FIG. 11A

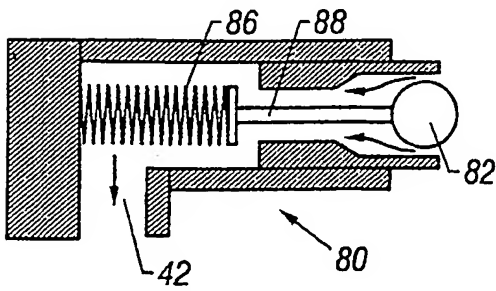


FIG. 10B

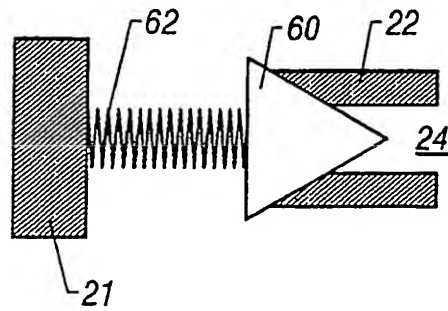


FIG. 11B

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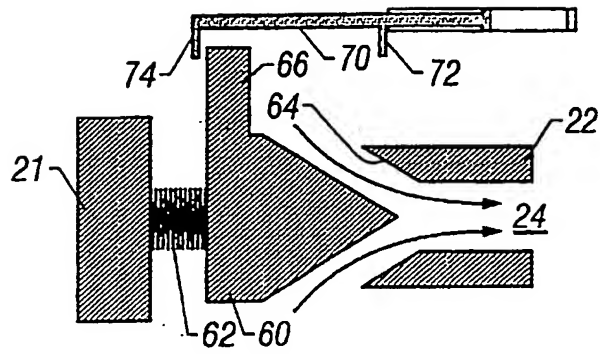


FIG. 12A

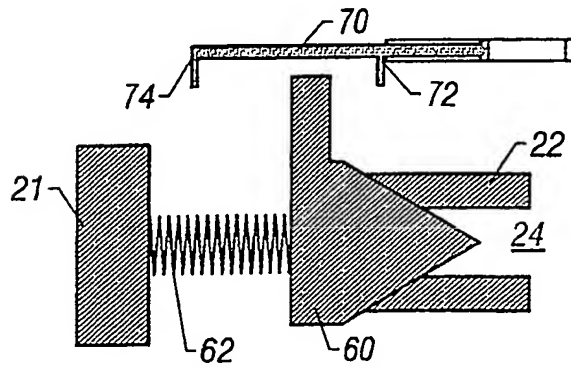


FIG. 12B

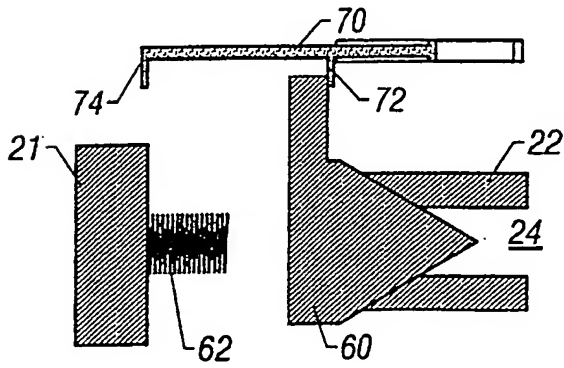


FIG. 12C

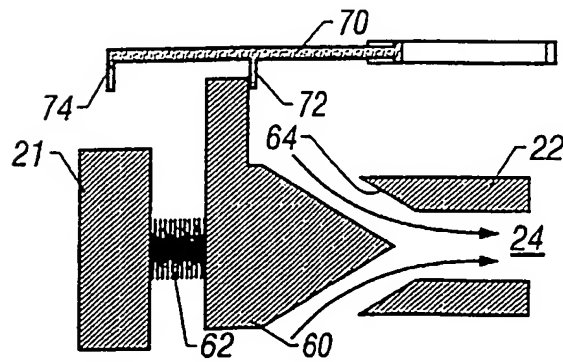


FIG. 12D

1 SAND SCREEN WITH ACTIVE FLOW CONTROL

2

3 BACKGROUND OF THE INVENTION4 FIELD OF THE INVENTION

5 The present invention relates to the art of well
6 completion methods and equipment for the production
7 of hydrocarbon fluids. More particularly, the
8 invention relates to methods and apparatus for
9 downhole regulation of hydrocarbon fluid production
10 rates.

11

12 DESCRIPTION OF RELATED ART

13 Bottom hole well tools are exposed to extremely
14 abrasive operating conditions. As hydrocarbon fluid
15 is released from the naturally occurring in situ
16 formation, sand, rock and other abrasive particles
17 are drawn with it. In deeper wells where the in
18 situ pressures are extremely high, the production
19 pressure drop between the formation and the flow
20 bore of the production tube is correspondingly high.
21 Such high pressure differentials in the presence of
22 a highly abrasive fluid rapidly erodes the
23 production control tools. Fluid velocity through
24 and over the tool surfaces, elements and apertures
25 is an exponential function of the pressure
26 differential drive. Hence, high pressure
27 differentials translate to high fluid velocities.
28 High velocity fluids entrained with abrasives
29 translates to high rates of erosion, wear and
30 failure.

31

1 Earth formation pressures and fluid production are
2 not, however, fixed properties. Both of these
3 properties change over time. Moreover, the changes
4 are not necessarily linear or in predictable
5 directions. The changes may be abrupt, irregular
6 and/or fluctuating. In cases of an elongated
7 production zone, often horizontal, the production
8 properties may change in one section of the
9 producing zone differently than those in another
10 section of the same producing zone.

11

12 Although downhole tools for limiting the production
13 rate of a production zone are known to the prior
14 art, such tools have a fixed configuration.
15 Production flow rate adjustments are usually made at
16 the surface. Downhole flow rate adjustment is
17 accomplished by removing the production tools from
18 the well bore and replacing a first fixed flow rate
19 tool with a second fixed flow rate tool of different
20 capacity.

21

22 It is, therefore, an object of the present invention
23 to provide active flow control, from the surface,
24 over production from gravel pack installations
25 through sand control screens down to an individual
26 screen.

27

28 Another object of the invention is provision of
29 means to regulate the inflow of fluids from a long,
30 horizontal petroleum reservoir to maximize
31 production.

32

1 Also an object of the present invention is provision
2 of means to terminate production flow from a
3 production screen or to divert flow from one screen
4 to another within the screen assembly.

5

6 A further object of the invention is provision of
7 means to adjust the production flow rate of a well.

8

9 SUMMARY OF THE INVENTION

10

11 These and other objects of the invention are served
12 by a tool that is associated with a production sand
13 screen to channel the screened production flow
14 through a flow control zone. Within the flow
15 control zone is a static flow control device that
16 reduces the fluid pressure differential over an
17 extended length of flow restrictive channel. At
18 either end of the flow control device are transverse
19 flow apertures disposed between the flow control
20 zone and the internal flow bore of the primary
21 production tube.

22

23 The apertures are flow controlled as either opened
24 or closed completely. This operational set allows
25 three flow states. When the apertures upstream of
26 the flow control device are closed and those
27 downstream are open, all production flow from the
28 associated screen must pass through the flow control
29 device. In doing so, the flow stream is required to
30 follow a long, helical path. Traversal of the flow
31 control device dissipates the pressure of state
32 within the fluid thereby reducing the pressure

1 differential across the production tool. The energy
2 potential of the pressure is converted to heat.

3

4 When apertures upstream of the flow control device
5 are open and those downstream are closed, production
6 flow is shunted directly from the flow control zone
7 into the internal flow bore of the primary
8 production tube. This operational state permits the
9 particular tool to run "open choke" but not
10 necessarily all tools in the formation.

11

12 The third flow state closes both apertures to
13 terminate all production flow from the associated
14 screen.

15

16 A preferred embodiment of the invention provides a
17 cylindrical tool mandrel within the internal bore of
18 a production tube that forms an annular flow channel
19 along the tube axis. Axially displaced from the
20 screen inflow area, is a circumferential band of
21 longitudinal stator columns that span radially
22 across the flow channel annulus to funnel the
23 annulus flow through gates between the stator
24 columns. Further displaced axially along the flow
25 channel annulus is a helically wound wall that also
26 spans radially across the flow channel annulus.
27 This helically wound wall is one embodiment of a
28 static flow control device.

29

30 Two sets of flow apertures through the mandrel wall
31 section link the annular flow channel with the
32 internal bore of the production tube. A first

1 aperture set is positioned axially displaced from
2 the static flow control device opposite from the
3 band of stator columns. A second aperture set is
4 positioned axially displaced from the band of stator
5 columns opposite from the flow control device. An
6 axially slideable ring substantially encompasses the
7 mandrel at an axial location adjacent to the stator
8 columns opposite from the static flow control
9 device. The ring is axially displaced by one or
10 more hydraulic cylinders. From one annular edge of
11 the ring projects a number of gate plugs. The
12 number of plugs corresponds to the number of gates.
13 The gate plugs overlies the second set of flow
14 apertures at all positions of axial displacement but
15 one.

16 At a first, axially stroked extreme position of the
17 ring, the second flow aperture set is open to
18 facilitate direct and unrestricted flow of
19 production flow from the channel annulus into the
20 internal bore.

21
22 At an intermediate axial position of the ring, the
23 plugs close the gates between the stator columns
24 thereby blocking flow to the first flow aperture
25 set. Also at this intermediate setting, the gates
26 block flow through the second set of apertures by
27 their lapped, overlay location. Consequently, at
28 the intermediate setting, no flow from the channel
29 annulus is admitted into the inner bore.

30
31 At a second axial extreme position, the plugs are
32 withdrawn from the gates to allow flow through the

1 static flow control device and into the first set of
2 flow apertures. However, at the second axial
3 extreme position the plugs continue to block flow
4 through the second set of flow apertures.
5 Consequently, the flow stream is required to
6 traverse the static flow control device to reach the
7 inner production tube bore.

8

9 BRIEF DESCRIPTION OF THE DRAWINGS

10

11 The advantages and further aspects of the invention
12 will be readily appreciated by those of ordinary
13 skill in the art as the same becomes better
14 understood by reference to the following detailed
15 description when considered in conjunction with the
16 accompanying drawings in which like reference
17 characters designate like or similar elements
18 through the several figures. Briefly:

19 FIG. 1 is an environmental schematic of the
20 invention;

21 FIG. 2 is a cross-sectional view of the invention in
22 a flow restrictive setting;

23 FIG. 3 is a cross-sectional view of the invention in
24 a flow obstructing setting;

25 FIG. 4 is a cross-sectional view of the invention in
26 a free-flow setting;

27 FIG. 5 is a plan view of the invention mandrel in
28 the restrictive flow setting;

29 FIG. 6 is a plan view of the invention mandrel in a
30 flow obstructing setting;

31 FIG. 7 is a plan view of the invention mandrel in a
32 free-flow setting;

1 FIG. 8 is a solenoid valve controlled embodiment of
2 the invention;
3 FIG. 9A is a cross-sectional view of a special case
4 solenoid valve pintle in a normal operating mode;
5 FIG. 9B is a cross-sectional view of a special case
6 solenoid valve pintle in a normal operating mode;
7 FIG. 10A is a hydraulic control schematic in the
8 hydraulic fluid flow blocking mode due to production
9 flow temperature;
10 FIG. 10B is a hydraulic control schematic in the
11 hydraulic fluid flow open mode due to production
12 flow temperature;
13 FIG. 11A is a production valve control system
14 responsive to a shape memory alloy driver to open a
15 production flow transfer aperture;
16 FIG. 11B is a production valve control system
17 responsive to a shape memory alloy driver to close a
18 production flow transfer aperture; and,
19 FIGS. 12A through 12D illustrate the operational
20 sequence of an automatic, thermally controlled valve
21 pintle.

22

23 DESCRIPTION OF THE PREFERRED EMBODIMENTS

24

25 With respect to the environmental schematic of FIG.
26 1, a production tube 10 is positioned within a
27 wellbore casing 12 to provide a continuous flow
28 conduit to the surface for a flow of fluids
29 extracted from a subterranean earth formation.
30 Along a formation fluid production zone, the casing
31 is perforated by apertures 14 for facilitation of
32 formation fluid flow into an outer production

1 annulus 18 between the interior wall of the casing
2 and the exterior wall of the production tube.
3 Longitudinally, the production annulus 18 may be
4 delimited by an outer packer 16.

5

6 Below the outer packer 16, the production tube 10
7 includes one or more sand screens 20 linked by flow
8 control housings 21. Internally of the screens and
9 flow control housings is a flow control mandrel 22.
10 A flow control annulus 23 is accommodated between
11 the interior walls of the flow control housings 21
12 and the exterior walls of the mandrel 22. The
13 continuity of the flow control annulus 23 may be
14 interrupted between sand screens 20 by an inner
15 packer 29.

16

17 Referring now to the partial cross-section of FIG. 2
18 and the schematic plan of FIG. 5, it is seen that
19 the wall of mandrel 22 is penetrated by two
20 circumferential sets of flow apertures 24 and 26.
21 Between the apertures 24 and 26, the outer mandrel
22 surface is profiled by surfaces that extend radially
23 out to juxtaposition with the interior surface of
24 the housing thereby substantially confining all
25 fluid flow along the flow control annulus 23.

26

27 A first exterior profile on the flow control mandrel
28 22 is a circumferential band of substantially
29 uniformly spaced stator columns 30. Between the
30 stator columns 30 are flow gates 32. A second
31 exterior profile on the flow control mandrel 22 is a

1 static flow control device 28 comprising a helically
2 wound channel between parallel walls.

3 Proximate of the first circumferential set of flow
4 apertures 24 is a circumferential set of gate plugs
5 36 extending from one edge of a base ring 34. The
6 opposite base ring 34 edge is attached to one or
7 more hydraulic, for example, struts 38.

8 Representatively, a strut 38 may comprise a cylinder
9 40 secured to the surface of mandrel 22 and a piston
10 rod 41 secured to the opposite edge of the base ring
11 38. The rod 41 may be extended axially from the
12 cylinder 40 to axially reposition the base ring 38
13 and gate plugs 36 by manipulations of pressurized
14 hydraulic fluid in one or two hydraulic fluid
15 conduits 42 and 43. Extensions of the conduits 42
16 and 43 to the surface enable these manipulations
17 from the surface if required. Downhole hydraulic
18 fluid power control may also be accomplished by
19 numerous other means and methods known to the active
20 practitioners of the art.

21

22 As may be observed from a comparison of FIGS. 5, 6
23 and 7, the rod 41 is stroked to provide the base
24 ring 38 and projecting gate plugs 36 an intermediate
25 position (FIG. 6) between two extreme positions
26 (FIGS. 5 and 7). At the FIG. 5 position, production
27 flow may travel along the control annulus 23, around
28 the gate plugs 36, through the gates 32 between
29 stator columns 30, and along the helically wound
30 flow channel of the static control device 38 into
31 the apertures 26. From the apertures 26, the fluid
32 enters the inner bore 11 of the production tube to

1 be lifted or driven by expanding gas to the surface.
2 To be noted from FIG. 5 is the overlaid relationship
3 of the apertures 24 by the gate plugs 36 thereby
4 effectively blocking fluid flow into the apertures
5 24.

6
7 When the gate plugs 36 are shifted to the
8 intermediate position shown by FIG. 6, the plugs 36
9 fill the flow channel space 32 between the stator
10 columns 30 thereby blocking flow into the static
11 flow control device 28. Consequently, no flow
12 reaches the apertures 26 for flow into the inner
13 bore 11. Moreover, gate plugs 36 continue to
14 overlies the aperture set 24 and block fluid flow
15 therethrough.

16
17 FIG. 7 illustrates the alternative extreme position
18 whereat the gate plugs 36 enter the gates 32 fully
19 thereby continuing the blockage of flow into the
20 apertures 26. However, as the gate plugs 36 move
21 deeper into the gates 32, the apertures 24 are
22 uncovered. At this arrangement, only a minimum of
23 flow resistance is imposed as the production flow
24 stream finds its way to the surface.

25
26 The alternative embodiment of the invention depicted
27 by FIG. 8 controls the opening and closing of
28 apertures 24 and 26 with electrically actuated
29 solenoid valves 44 and 46. For unrestricted flow,
30 valves 44 would be opened and valves 46 closed. For
31 maximum flow resistance, Valves 44 would be closed
32 and valves 46 opened to force the production flow

1 through the static flow restriction device 28. For
2 zero flow, of course, both valves 44 and 46 are
3 closed.

4
5 As a permutation of the FIG. 8 embodiment, FIGS. 9A
6 and 9B illustrate a solenoid valve 48 having an
7 electrically energized winding 50 secured in the
8 housing 21 for selectively translating a pintle 52
9 into or out of a flow aperture 24 or 26.
10 Distinctively, the pintle 52 is centrally hollow.
11 The hollow core 54 of the pintle stem is closed by
12 plug 58 at the end that penetrates into the inner
13 flow bore 11. However, the hollow core is open to
14 the control flow annulus 23 by apertures 56 when the
15 pintle 52 is at the closed aperture 24 position. In
16 the event of power or control failure of a nature
17 that prevents a desired opening of a closed valve
18 48, a restricted by-pass flow may be obtained by
19 deployment of a shear dart from the surface along
20 the inner bore 11 to mechanically break the end of
21 the pintle stem and expose the hollow core 54.

22
23 As the flow of the production fluid transfers energy
24 to the flow control equipment, frictional heat is
25 generated. Consequently, the equipment temperature
26 bears a functional relationship to the production
27 flow rate. Based on the fact that operating
28 temperatures of flow control devices change as a
29 function of flow rates, automated downhole control
30 of such devices may be accomplished with valves that
31 respond operationally to the temperature changes.
32 FIGS. 11A and 11B illustrate one embodiment of this

1 principle wherein a valve pintle element 60 is
2 operatively driven by a shape memory alloy 62 into
3 cooperative engagement with a valve seat 64 to
4 directly control production flow through an aperture
5 24. FIG. 11A schematically illustrates the valve
6 elements in a production flow condition wherein the
7 flow rate through the flow aperture 24 is
8 insufficient to generate heat at a rate that is
9 sufficient to expand the shape memory alloy valve
10 driver 62. In contrast, FIG. 11B schematically
11 illustrates a non-flow condition wherein the shape
12 memory alloy driver 62 has expanded due to excessive
13 heating and pushed the pintle 60 into engagement
14 with the aperture 24 seat 64.
15
16 The invention embodiment of FIGS. 12A-12D modifies
17 the foregoing control structure further with a
18 mechanically controlled override. In this design,
19 the valve pintle 60 includes, for example, an
20 engagement tab 66 that cooperates with shift fingers
21 72 and 74 that depend from a selectively stroked
22 hydraulic strut. FIG. 12A schematically illustrates
23 the production flow condition in which the shape
24 memory alloy driver 62 is contracted and the pintle
25 60 is withdrawn from the valve seat 64. The strut
26 70 is at an intermediate position with the shift
27 finger 74 in close proximity with the engagement tab
28 66. FIG. 12B schematically illustrates a condition
29 change wherein flow generated heat has expanded the
30 alloy driver 62 and caused the pintle 60 to be
31 translated into closure contact with the valve seat
32 64.

1
2 Represented by FIG. 12C is a disfunction condition
3 wherein the alloy driver 62 has cooled and
4 contracted but the pintle 60 has not drawn away from
5 the seat 64 to open the aperture 24. FIG. 12D
6 schematically illustrates the override of the shape
7 memory alloy 62 with an engagement of the pintle tab
8 66 by the strut finger 72 to forceably push the
9 pintle 60 away from the valve seat 64.

10

11 The inventive concepts represented by FIGS. 10A and
12 10B apply the concepts of automatic flow regulation
13 with shape memory alloy control elements to the
14 hydraulic control lines 42 and/or 43 in the FIG. 2
15 embodiment. FIG. 10A represents a check valve
16 control 80 in the hydraulic strut power line 42. A
17 ball closure element 82 is pressure differentially
18 biased against the valve seat 84 to block flow
19 through the conduit 42 into the strut 38. The
20 closure condition prevails while the shape memory
21 alloy driver 86 is cool and contracted. When the
22 flow control elements are sufficiently heated by
23 excessive flow velocity, the memory alloy driver 86
24 expands against the disengagement probe 88 to push
25 the ball 82 off the seat 84 and allow hydraulic flow
26 into the strut 38. Resultantly, the strut rod 41
27 and gate plug 36 are displaced in a direction to
28 restrict or terminate the excessive flow.

29

30 Modifications and improvements may be made to these
31 inventive concepts without departing from the scope
32 of the invention. The specific embodiments shown

1 and described herein are merely illustrative of the
2 invention and should not be interpreted as limiting
3 the scope of the invention or construction of the
4 claims appended hereto.

CLAIMS

1. A method of regulating the flow of hydrocarbon fluid from a producing zone into a production well, said method comprising the steps of:
 - a. providing a fluid production tube in a wellbore having a formation fluid production zone, said production tube having a production flow bore therein;
 - b. providing an intermediate fluid flow channel within said production tube between said production zone and said production flow bore;
 - c. providing a static flow restriction within said intermediate channel;
 - d. providing a first flow aperture between said intermediate channel and said production flow bore downstream of said flow restriction;
 - e. providing a second flow aperture between said intermediate channel and said production flow bore upstream of said flow restriction; and,
 - f. selectively obstructing fluid flow through either or both of said flow apertures.
2. A method as described by claim 1 wherein said flow apertures are selectively opened and closed.
3. A method as described by claim 1 wherein fluid flow through said first aperture is obstructed

1 by a selective obstruction of flow through said
2 flow restriction.

3

4 4. A well tool for regulating the flow rate of
5 fluid from an earth producing zone, said tool
6 comprising:

- 7 a. a well fluid production tube having a
8 production flow channel therein and a
9 production fluid flow screen for passing
10 fluid from said producing zone into said
11 production flow channel;
12 b. an intermediate flow channel between said
13 flow screen and said production flow
14 channel;
15 c. a static flow restriction in said
16 intermediate channel;
17 d. a first fluid flow aperture between said
18 intermediate flow channel and said
19 production flow channel disposed
20 downstream of said static flow
21 restriction;
22 e. a second fluid flow aperture between said
23 intermediate flow channel and said
24 production flow channel disposed upstream
25 of said static flow restriction; and
26 f. a selectively positioned flow obstruction
27 for substantially preventing fluid flow
28 through either or both of said flow
29 apertures.

30

- 1 5. A well tool as described by claim 4 wherein
2 said selectively positioned obstruction is
3 driven by a shape memory alloy.
4
- 5 6. A well tool as described by claim 4 wherein
6 said selectively positioned obstruction is a
7 solenoid valve operator respective to said flow
8 apertures.
9
- 10 7. A well tool as described by claim 6 wherein
11 said valve operator comprises a flow by-pass
12 element.
13
- 14 8. A well tool as described by claim 7 wherein
15 said by-pass element comprises a valve stem
16 conduit having an open entry aperture in said
17 intermediate flow channel and a plugged exit
18 aperture in said production flow channel.
19
- 20 9. A well tool as described by claim 4 wherein
21 said flow obstruction comprises a fluid flow
22 gate within said intermediate flow channel for
23 obstructing fluid flow into said flow
24 restriction.
25
- 26 10. A well tool as described by claim 9 wherein
27 fluid flow through said fluid flow gate is
28 controlled by a selectively positioned plug.
29
- 30 11. A well tool as described by claim 10 wherein
31 said selectively positioned plug also obstructs
32 fluid flow through said second flow aperture.

- 1
- 2 12. A method of regulating the flow of production
- 3 fluid from a fluid producing zone into a
- 4 production conduit comprising the steps of:
- 5 a. providing first and second fluid flow
- 6 routes for production fluid from a
- 7 producing zone into a production conduit;
- 8 b. providing greater resistance to flow along
- 9 said second flow route relative to flow
- 10 along said first flow route; and,
- 11 c. providing a first selectively engaged flow
- 12 obstruction along said first flow route.
- 13
- 14 13. A method as described by claim 12 further
- 15 providing a second selectively engaged flow
- 16 obstruction along said second flow route.
- 17
- 18 14. A method as described by claim 12 wherein said
- 19 first and second flow routes extend from an
- 20 intermediate fluid flow channel between said
- 21 fluid producing zone and said production
- 22 conduit.
- 23
- 24 15. A method as described by claim 12 wherein said
- 25 first flow obstruction is manually engaged.
- 26
- 27 16. A method as described by claim 12 wherein said
- 28 first flow obstruction is automatically
- 29 engaged.
- 30

- 1 17. A method as described by claim 12 wherein said
- 2 first flow obstruction is automatically engaged
- 3 as a function of a production fluid flow rate.



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Application No: GB 0201645.9
Claims searched: 1 to 17

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Examiner: Matthew Perkins
Date of search: 17 May 2002

Patents Act 1977 Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.T): E1F: FLE, FLF, FLH, FLJ, FLK, FLM

Int CI (Ed.7): E21B

Other: Online: WPI, EPODOC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2361017 A (PUMP TOOLS LTD.) See abstract and figures	-
A	GB 2351748 A (MAERSK) See abstract, figures and page 2 line 23 to page 5 line 21.	-
A	GB 2314866 A (BAKER HUGHES INC.) See figures, abstract and page 4 line 6 to page 5 line 17.	-

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.

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A Document indicating technological background and/or state of the art.
P Document published on or after the declared priority date but before the filing date of this invention.
E Patent document published on or after, but with priority date earlier than, the filing date of this application.